

Review

A Study about Tooth Size and Arch Width Measurement

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Abstract: Many model analyses methods for measuring tooth size discrepancies, even though they are not always used have been carried out by many authors and formulated for the predetermination of arch size. On the basis of their findings many studies were carried out to find out its reliability, few researchers agreed to the statement made and few pointed out their lack of agreement. Bolton's method of diagnosing tooth-size discrepancy has been widely used in scientific studies since its publication. Cast analysis is required for all potential orthodontic patients, whether problems are moderate or severe. It is done to evaluate symmetry, alignment (crowding, spacing) and tooth size analysis.

Key words: Tooth size, Arch size, Width measurement

1. Bolton's analysis

Bolton¹⁾ his study of tooth size analysis is an intermaxillary ratio analysis designed for the purpose of localizing differences in tooth size and by comparing it with normal standard, the deficient arch is determined. A proper balance should exist between the mesio-distal tooth size of the maxillary and mandibular arches to ensure proper interdigitation, overjet, overbite at the completion of orthodontic treatment. Bolton established anterior ratio (AR) and overall ratio (OR).

OR can be calculated by dividing the sum of mandibular twelve teeth (left first molar to right first molar) by sum of maxillary twelve teeth (first molar to first molar). Bolton's OR is 91.3 percent, if the value obtained is less than 91.3 percent the discrepancy is in maxillary teeth and if it exceeds the normal the discrepancy is in mandibular teeth.

AR is established by dividing mandibular six anterior teeth (right canine to left canine) by maxillary six anterior teeth (canine to canine). Bolton's AR is 77.2 percent, if the value is less than 77.2 percent the discrepancy is in maxillary arch and if more than 77.2 percent the discrepancy is in mandibular arch.

2. Pont's analysis

Pont²⁾ stated that for normal dental arch there is a constant relationship exist between the sum of the mesiodistal widths of the permanent maxillary incisors (SI) and the interpremolar or intermolar arch widths. This is expressed by the following formulae:

$$\S \text{ Interpremolar arch width} = \text{SI} / 0.80$$

$$\S \text{ Intermolar arch width} = \text{SI} / 0.64$$

His study was done on a French population, the sample size and selection criteria were not described.

Diagnostic records for orthodontic purpose

Diagnostic records have been categorized into 3 types³⁾.

1. Records for intraoral evaluation

- (1) Intraoral photograph are commonly taken to record any hard and soft tissue lesions.
- (2) Panoramic intraoral radiograph are taken to see any pathologic lesion, supernumerary or impacted tooth.
- (3) Bite wing radiographs especially for children and adolescent to evaluate interproximal caries, and for adult to see the periodontal condition.
- (4) Transcranial and Laminagraphic TMJ films are taken for patients having symptoms of dysfunction.

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2. Records for occlusal evaluation

Dental casts are very important records for occlusal evaluation of the occlusion and the wax bite of patient's centric occlusion and casts are articulated. Dental cast should be trimmed so that the bases assume symmetric shape.

3. Records for evaluation of facial proportions

- (1) Facial photographs
- (2) Lateral cephalometric radiograph

Normal occlusion

Correct occlusion is not a static condition. Attrition plays important role in changing the anatomy of occlusion. Angle⁴⁾ in his study of morphology of tooth described the ideal normal occlusion. Angle's system of classifying malocclusion was a tremendous step forward because it provided clear simple definition of normal occlusion in the natural dentition thereby a way to distinguish normal occlusion from malocclusion. Angle postulated that the upper first molars were the key to occlusion. He classified malocclusion according to the relationship between upper and lower first molar. Angle's classification has four classes,

1. Normal occlusion: Mesio Buccal cusp of upper first molar occludes the buccal groove of lower first molar and the teeth were aligned on a smoothly curving line of occlusion.
2. Class I: first molars are in normal relationship but line of occlusion is not correct because of malposed or rotated teeth or any other causes.
3. Class II: lower molar distally positioned relative to upper first molar.
4. Class III: lower molar mesially positioned relative to upper molar³⁾.

Ackerman and Proffit⁵⁾ in 1960s formalized the system of informal addition to the Angle method by identifying five major characteristics of malocclusion that systematically described in classification which is now widely used. It incorporates the following approaches which overcome the major weakness of Angle scheme.

1. An evaluation of crowding and asymmetry with in the dental arches.
2. Incisor protrusion.
3. The relationship between protrusion and crowding.
4. Transverse and vertical as well as anteroposterior planes of space.
5. Information about skeletal jaw proportion.

They classified malocclusion in following way,

1. Intra arch alignment: a. Ideal b. Crowding c. Spacing.
2. Profile: a. Anterior divergent b. posterior divergent c. convex d. straight e. concave.
3. Transverse deviation: a. Buccal b. Palatal c. Unilateral d. Bilateral e. dental f. skeletal.

4. Sagittal deviation: a. class I anterior displacement b. class II division I c. class II division II d. class III e. dental f. Skeletal.
5. Vertical deviation: a. Openbite anterior b. Openbite posterior c. Deepbite anterior d. collapsed bite posterior e. Dental f. Skeletal.

American orthodontic scholar Andrew⁶⁾ did 120 model analysis and set six criteria for ideal normal occlusion (Andrew's six keys of normal occlusion). He described the interarch relationship, crown angulation, crown inclination, tooth rotation, tight contacts and curve of spee.

Findings of previously done tooth size measurement, Bolton's analysis and Pont's analysis

1. Tooth size measurement

Ballard⁷⁾ studied 500 model and showed that in 90% of the sample there is discrepancy in mesiodistal diameter between teeth of the left and the right side, amounting to 0.25 millimeter or more. Neff⁸⁾ did his study on sample of 300 with malocclusion and developed the "anterior coefficient" which is obtained by measuring the mesiodistal diameters of six upper anterior and divided by mesiodistal diameter of six lower anterior teeth. He concluded that the maxillary anterior were 18 percent to 36 percent larger than mandibular six anterior and in his next study⁹⁾ he stated if the maxillary six anterior teeth are 22% or more larger than the lower anterior six teeth, the relation is acceptable if it does not exceed 36%. If the relationship is below 22%, a reduction in the size of mandibular tooth masses (stripping or an extraction) is necessary to obtain. Howes¹⁰⁾ concluded, in his study on 125 cases, that if the ratio of premolar basal arch width (PMBAW) to the combined width of maxillary right first molar to left first molar, is 44 percent, it may be assumed that apical base is adequate, if the ratio is between 37 to 44 percent adequacy of basal bone is questionable and if the ratio is less than 37 percent extraction is indicated.

2. Bolton's analysis

Bolton^{1, 11)} did his study on 55 samples from University of Washington, he computed for the tooth size ratios between maxillary and mandibular teeth and suggested AR from both canine to canine and OR from first molar to first molar. To achieve optimum occlusion with their respective mean values, AR 77.2% and OR 91.3%. Bernabe et al¹²⁾ studied on 200 children from Lima, Peru, who had complete permanent dentition, with no previous or active orthodontic treatment. The 2 SD range from the Bolton mean did not predict clinically significant anterior and total tooth width ratio discrepancies. Clinically significant anterior and total tooth-size discrepancies were present in approximately one third of the sample. Crosby and Alexander¹³⁾ in their mixed gender sample of 109 orthodontically treated patients (30 cases with class I malocclusion, 30 having class II div 1, 29 class II div 2 and 20 class II surgery). Among class I malocclusion 16.7%

had AR 2 SD outside of Bolton's mean (10% above +2 SD and 6.7% below -2 SD). Among class II div I malocclusion cases 23.4% had AR outside 2 SD from Bolton's mean and 13.3% had OR outside 2 SD of Bolton's mean. Among class II surgery cases 6.8% had OR outside Bolton's mean (3.4% were above and 3.4% below). Crosby D.R. and Alexander C.G. did not specify the occlusal characteristics of their orthodontic sample. They found no statistically significant differences when comparing Class I and Class II subjects and did not evaluate Class III patients in their study. Sperry et al.¹⁴⁾ studied on 38 patients orthodontical treated for mandibular prognathism and 26 subjects with class I malocclusion and 26 subjects with class II malocclusion from University of Minnesota, he analyzed the Bolton ratios for groups of Class I, Class II, and Class III cases. The skeletal patterns were not mentioned, although some of the Class III cases were treated surgically. Male and female subjects were not differentiated. The OR showed a mandibular tooth size excess for the Class III patients.

Arouju et al.¹⁵⁾ studied on 300 individuals from Belo Horizonte, Brazil, with Angle Class I and Class III show significantly greater prevalence of tooth size discrepancies than do individuals with Class II for OR and AR. Mean AR size discrepancy for Angle Class III subjects was significantly greater than for Class I and Class II subjects. Nourallah et al.¹⁶⁾ did a study on 55 Syrian patients (35 male and 20 female) all having neutral occlusion of permanent dentition with Angle class I molar and canine relation and found that the mean value for anterior ratio and overall ratio were similar to original data of American population as found by Bolton. Stifter et al.¹⁷⁾ studied on 57 American dental student of Ohio State University and 8 Navaho Indian all having normal class I normal occlusion and obtained similar result as that of Bolton for AR and OR. Margherita et al.¹⁸⁾ studied on 54 Dominican-American orthodontic patients, 36 men and 18 women, pretreatment orthodontic models were taken and found the overall tooth size ratio was equivalent to the original Bolton overall ratio, but the anterior tooth size ratio was larger than the Bolton anterior ratio. The difference was statistically significant and suggests the need for more specific standards for the Dominican.

Tancan et al.¹⁹⁾ did his study on 150 Turkish subjects with Angle class I normal occlusion, Bolton's original data do not represent Turkish people. A discrepancy in the OR was found in 18% of Turkish subjects with Bolton's ratio and anterior ratios outside 2 standard deviations from the Bolton mean were found in 21.3% of Turkish population. Semra et al.²⁰⁾ studied on 125 Turkish population. On normal occlusion group he found, the anterior ratio 77.95 ± 2.35 , and the overall ratio 91.95 ± 2.20 , the results of this study show that the overall and anterior Bolton ratios can be applied to a Turkish population. Richardson and Malhotra²¹⁾ studied on 162 American Negroes and found the ratio of the mandibular dentition of the maxillary dentition was 94% in both sexes. The ratio of the sum of the widths of the canines and incisors

of the mandibular dentition to those of the maxillary dentition was 77%. Vanessa et al.²²⁾ studied on 100 subjects (30 female, 70 male) of Spanish population with Angle Class I occlusion and concluded 21% of the subjects had a significant anterior discrepancy and 5% had a total discrepancy. Difference between Spanish values and Bolton's values were significant, and suggested that specific standard for Spanish people might be needed.

3. Pont's analysis

Pont²⁾ stated that his study was performed on a French population, the sample size and selection criteria were not described. He concluded that his work should be applied to different ethnic groups for verification or correction. Pont's index remains highly controversial. Some investigators (Stifter¹⁷⁾, Gupta et al.²³⁾ supporting its use to predict arch widths, while other authors (Worms et al.²⁴⁾, Dalidjan et al.²⁵⁾, Iyad K Al-Omari et al.³⁾) suggested that Pont's Index is not reliable and should not be used for clinical purposes. Worms et al.²⁴⁾ studied Navajo-Indians and American dental students, low correlations were found between the actual arch widths and those calculated using Pont's formulae. In most cases the actual values were less than the predicted values. They concluded that use of Pont's Index for clinical purposes could not be recommended. Dalidjan et al.²⁵⁾ applied the index on three different populations, Australian Aborigines, Indonesians, and white Australians, and the results discouraged the clinical use of Pont's Index. Iyad K Al-Omari et al.³⁾ studied the reliability of Pont's index was studied on Jordanian population on a sample of 144 Jordanians (71 males and 73 females; mean age of 15.5 years) with normal occlusions and concluded the correlation coefficients between the measured arch width values and the corresponding values calculated according to Pont's Index were low in all cases for males and females, with r values ranging from 0.25 to 0.39. Gupta et al.²³⁾ applied the index on an Indian population and found a significant relationship between the sum of the incisor widths and arch widths.

Tooth-size discrepancies and gender

Various studies have investigated ethnic and sex^{26,27)} differences in the intermaxillary tooth ratios. As in other physical properties of human beings, teeth vary in size between the two sexes and among individuals from different geographical regions. Few researchers have found significant difference between male and female however few found no difference.

1. Findings showing no difference between male and female

Sercan²⁸⁾ in a skeletally similar sample of 152 Turkish subjects found no statistically significant differences for the Bolton's AR and OR means among the Angle Class I, II, and III groups between male and female. Abduhl et al.¹⁶⁾ on 55 Syrian having Angle class I occlusion found the mean values for the AR and OR for male and female subjects were very similar and did not differ

significantly. Uysal et al.²⁹⁾ studied on comprised 560 individuals with the following distribution: Class I (6 males and 150 females); Class II, division 1 (75 males and 82 females); Class II, division 2 (11 males and 23 females); and Class III (58 males and 55 females) no significant sexual dimorphism between subcategories of malocclusion, the sexes were combined for each group for anterior and overall ratios. In Semra et al.²⁰⁾, the mean values for the anterior and overall ratios for male and female subjects did not differ significantly. Richardson and Malhotra²¹⁾ found among American Negroes no difference between male and female in over all tooth size ratio and anterior tooth size ratio. Al-Tamimi and Hashim³⁰⁾ also found no sexual difference in Bolton ratios in a relatively small sample of 65 Saudi. Vanessa et al.²²⁾ on Spanish subjects found no significant differences were found in anterior and total tooth-width ratios between sex.

2. Findings showing difference between male and female

Lavelle³¹⁾ showed that the total and anterior ratios were both greater in males than in females. However, sex differences were less than 1%. Arya et al.³²⁾ showed that there were differences in tooth size between sex. Significant sex differences were shown for the overall ratio. Santoro et al.¹⁸⁾, on 54 Dominican Americans orthodontic patients, found male crown measurements were slightly larger than the female. Tancan et al.¹⁹⁾, 150 Turkish subjects for normal occlusion group found significant sex differences for the OR (showing larger mandibular arch segment for males). Richardson et al and Malhotra et al.²¹⁾ found that the teeth of black North American males were larger than those of females for each type of tooth in both arches, but there were no differences in anterior or posterior inter-arch tooth-size proportion. The maxillary first premolars were larger than the second premolars, while the mandibular second premolars were larger than the first premolars. The first molars were larger than the second molars in both the maxillary and mandibular arches in both sexes. Smith et al.³³⁾ found that males had larger ratios than females. However, these differences (0.7% for OR and 0.6% for AR) were small, being much less than 1 standard deviation from Bolton's sample. Iyad K. Al-Omari et al.³⁾ studied for application of Ponts index on Jordanian, there was no significant difference between males and females in incisor widths. Females, however, had significantly smaller values for maxillary and mandibular arch widths.

Tooth-size discrepancies and racial groups

It has been suggested that tooth-size discrepancies differs between various racial or ethnic groups. Bolton¹⁾ based his study upon a heterogeneous Caucasian population sample so provides no information relating to other racial groups. Lavelle³¹⁾ studied tooth-size ratios on 120 subjects among them 40 were Caucasoid (British), 40 Negroid and 40 Mongoloids having excellent occlusions. These 3 terms for these racial groups are originally

anthropological and are based on skull dimensions. They can be considered equivalent to the terms White, Black and Far Eastern. Both the overall and anterior average ratios were greater in Negroid than in Caucasoid, those for Mongoloids being intermediate so the means are a good guide to the ideal mean ratio to give a good fit for a racial group. Merz et al.³⁴⁾ investigated tooth diameters and arch perimeters and found that Black patients have larger mesiodistal tooth widths and larger dental arch perimeters than white patients. The data of Santoro¹⁸⁾ were consistent with the values available from a previous study on residents of the Dominican Republic. Dominican Americans' mesiodistal dental lengths resemble more closely those of African Americans, with larger mesiodistal dental lengths when compared to white Americans. However, the overall tooth size ratio was equivalent to the original Bolton overall ratio, but the anterior tooth size ratio was larger than the Bolton anterior ratio. The difference was statistically significant and suggests the need for more specific standards for the Dominican population. A more recent study by Smith et al.³³⁾ on inter-arch tooth-size relationship of 3 populations found that whites displayed the lowest overall ratio (92.3%), followed by Hispanics (93.1%), and Blacks (93.4%). The anterior ratio, however, was statistically significantly larger in Hispanics (80.5%) than Blacks (79.3%). There appears to be a trend of a larger overall ratios in black populations. All ethnic group names should be capitalized.

Variations in tooth size using different types of measurement method

Shellhart et al.³⁵⁾ evaluated the reliability of the Bolton analysis when performed using 2 instruments: needle pointed divider and Boley gauge and also investigated the effect of crowding on measurement error. They found that clinically significant measurement errors could occur when the Bolton tooth-size analysis is performed on casts that have at least 3 mm of crowding, a factor that should lead clinicians to undertake a tooth-size discrepancy analysis in substantially crowded cases only when the teeth have been aligned.

The introduction of digital models offers the orthodontist an alternative to the plaster study models. Plaster study models are a standard component of orthodontic records. Santoro et al.³⁶⁾ used the sample to compare plaster models from consecutive alginate impressions consisted of 20 randomly selected subjects, each with all permanent teeth from first molar to first molar erupted, no missing teeth from first molar to first molar, and no existing orthodontic appliances 1 set of model was measured on the digital models with the analysis tools provided by OrthoCAD, to the nearest 0.1 mm. There was a statistically significant difference between tooth width measurements made by the 2 methods, with all the digital model measurement smaller than the corresponding plaster model measurements. The greatest mean difference was (0.38mm). Paredes et al.³⁷⁾ used a new digital method for

measuring tooth sizes and for calculating the Anterior (ABI) and the Overall (OBI) Bolton Index was tested on 100 sets of study dental casts of the permanent dentition in a Spanish sample and compared with the traditional method. The proposed digital method is as sensitive and accurate as the traditional method for calculating the Bolton indices. It is faster and easier to carry out and offers all the advantages associated with computer methods, such as the storage of images and data for subsequent use. Stevens et al.³⁸⁾ found measurement associated plaster versus digital models showed a clinically significant difference. Schirmer and Wiltshire³⁹⁾ and Champagne⁴⁰⁾ compared measurement made manually on casts with those made on digitized casts obtained from a photocopier. They concluded although photocopies are easy to handle, manually measuring teeth with a calibrated gauge produces the most “accurate, reliable, and reproducible” measurements. Bhatia and Harrison⁴¹⁾ studied the performance of the “travelling microscope”, an apparatus modified to measure dental casts, and concluded that the method was more precise than some alternatives. Martensson and Ryden⁴²⁾ investigated a holographic system for measuring dental casts. The method was shown to be more precise than previous methods, and the authors believed that it would also save storage space. However although microscope and holographic systems had some advantages, they did not prove to be practical in clinical practice and never became popular. Ho and Freer⁴³⁾ proposed that the use of digital caliper with direct input into the computer program can virtually eliminate measurement transfer and calculation errors, compared with analysis that requires dividers, rulers and calculators, although the same measurement error may be associated with the positioning of the calipers on the teeth. Tomassetti et al.⁴⁴⁾ performed a study using manual measurements with a Vernier caliper and 3 computerized methods. Quick Ceph was the quickest method followed (in order) by HATS, Ortho CAD and Vernier calipers. However, Quickceph gave results which gave the greatest mean discrepancy from Vernier calipers (although not statistically significant) and which were least correlated with the Vernier caliper results. Zilberman et al.⁴⁵⁾ also compared the measurement using digital calipers with OrthoCAD. Measurement with digital calipers produced the most accurate and reproducible results and OrthoCAD’s accuracy was considered clinically acceptable.

Factors influencing variation in tooth size

Variation in tooth size is under a high degree of genetic control. There have been difficulties in separating the various genetic and environmental factor. Baydas et al.⁴⁶⁾ studied on subjects who applied for orthodontic treatment and their sibling (106 female and 78 male), subjects were grouped according to gender male to male 24 pairs, female to female 38 pairs and male to female 30 pairs to find effect of heritability on Bolton tooth-size discrepancy, and found that if a patient has a tooth-size discrepancy, the same problem may also be seen in sibling of same gender. So it should

be remembered that it is not the etiology of the resemblance between the siblings, but the resemblance itself that should be taken into consideration. Among other factors nutrition also found to have role in variation of tooth size and teeth formation mechanism closely related to location and inadequate nutrition in the teeth of extreme importance. Race has important role in variation of tooth size and gender difference also shows variation in tooth size.

Conclusion

This review was done for studying what previous researchers have stated about the tooth size discrepancies, race and gender related tooth size discrepancy, different type of measurement methods to promote accuracy of tooth size measurement. Few studies showed statistically significant differences between gender and racial group and whereas other studies showed no significant difference. And the different types of the measurement tools seem to have a clinically significant influence on Bolton’s tooth-size ratios. So the studies based on Bolton analysis for people of different races and different countries and determination of their own normative value are very useful. While in Pont²⁾ analysis the author himself stated that the research was done only for French population to find the relation between sum of the upper permanent incisors and intermolar and interpremolar width and suggested to do the analysis on various other ethnic groups, this study is also useful.

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